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UTILITY OF ELEMENTAL GEOCHEMICAL DATA IN CORRELATION AND PROVENANCE STUDIES OF PLEISTOCENE MATERIALS: A CASE STUDY IN STEARNS COUNTY, CENTRAL MINNESOTA

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UTILITY OF ELEMENTAL GEOCHEMICAL DATA IN CORRELATION AND PROVENANCE STUDIES OF PLEISTOCENE MATERIALS: A CASE STUDY IN STEARNS COUNTY, CENTRAL MINNESOTA

By

G.B. Morey, R.S. Lively, and Gary N. Meyer

INTRODUCTION

Geochemical attributes, especially minor, trace, and rare-earth elements, are commonly used to characterize various kinds of sedimentary rocks and to elucidate their provenance. Similar techniques have been applied to glacial materials with varying degrees of success. In Minnesota, for example, Martin and others (1989, 1991) concluded that few if any geochemical elements were useful for correlating tills across large areas. In contrast, Gowan (1998), in a study of six till units from central Minnesota, concluded that geochemical attributes were useful in delineating stratigraphic units and their provenance. Results of a similar study in southwestern Minnesota (Patterson and others, 1995) were inconclusive.

The geochemical studies undertaken to date in Minnesota have utilized the silt- and clay-size fraction as a sample medium and Atomic Adsorption spectrometry or Inductively Coupled Plasma emission spectrometry as the principal analytical technique. Unfortunately, both techniques require that the sample medium be dissolved prior to analysis, which can limit the value of the resulting data. For example, relative to the composition of the sample matrix and the particulates, certain minerals and elements may be selectively leached or incompletely dissolved, or spectral signals from some concentrated elements may interfere with weaker signals from less abundant elements. Such problems are best addressed by the use of replicates and standards developed from materials similar to those being analyzed. To our knowledge, sets of material standards that could be used to calibrate the various analytical methods have not been developed for Pleistocene sediments in Minnesota.

In this study we avoided problems associated with partial dissolution and interference by using Instrumental Neutron Activation Analysis (INAA) techniques (XRAL Activation Services Inc., Ann Arbor, Michigan). We analyzed 123 subsurface samples from five drill sites in Stearns County, east-central Minnesota, for 32 elements (Fig. 1). The results in this report are not directly comparable with those of Martin and others (1988), Gowan (1998), and Patterson and others (1995), because they were obtained on whole-rock samples from which only clasts of pebble or larger size had been removed. Nonetheless, the data provide insight into the utility of geochemical techniques to investigate provenance and transport patterns of glacial materials. The complete file of analytical data is summarized in the Appendix.

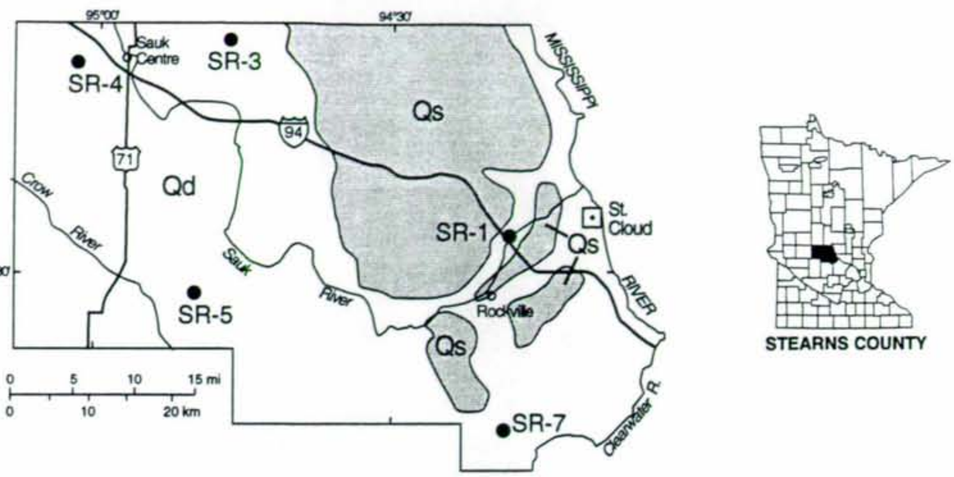


Figure 1. Simplified surfical geologic map of Stearns County, Minnesota, showing the locations of drill holes discussed in the text. Unit Qd, deposits of Riding Mountain provenance (Des Moines lobe); unit Qs, deposits of Superior provenance (Superior lobe). Modified from Meyer and Knaeble (1996). Principal facts and geological and geophysical logs of the boreholes are summarized in the appendix of Meyer and Swanson (1996).

Table 1. Physical attributes of glacial deposits in Stearns County classified by ice sector and sediment provenance.

[Modified fom Meyer and Knaeble, 1996]

Ice sector	Keewatin (northwest)		Labrador (northeast)	
Provenance	Riding Mountain	Winnipeg	Rainy (Wadena)	Superior
Till texture	Loamy	Loamy to clayey	Sandy	Sandy
Color				
Oxidized	Yellow to olive brown	Yellow brown to olive brown	Yellow to yellow brown	Brown to red brown
Unoxidized	Gray	Gray, dark gray, green gray	Gray	Gray to red gray
Pebble type				
Carbonate	Common	Uncommon to abundant	Uncommon to common	Rare to common
Gray-green rocks	Uncommon to common	Uncommon to common	Uncommon to common	Common to abundant
Red felsite & sandstone	Absent to uncommon	Absent to uncommon	Rare to uncommon	Uncommon to common
Gray shale	Common	Absent to uncommon	Absent to rare	Absent

REGIONAL STRATIGRAPHIC SETTING

Several subsurface stratigraphic studies (summarized in Meyer, 1997) have established that during Pleistocene time glacial ice flowed into Minnesota from two major source areas in northern Canada—the Keewatin sector to the northwest and the Labrador sector to the northeast. Ice entering Minnesota from the Keewatin sector passed over two geologically distinct terrains: the Riding Mountain provenance to the west and west-northwest, and the Winnipeg provenance to the north-northwest and north. Tills of Riding Mountain provenance contain a moderate to large quantity of Cretaceous clasts derived mostly from the Pierre Shale, and a moderate quantity of Paleozoic carbonate clasts (Table 1). Tills characteristic of the Winnipeg provenance are subdivided into two groups: the first contains a small to moderate proportion of Cretaceous and Paleozoic carbonate detritus; the second, a small proportion of Cretaceous detritus and a moderate to large proportion of Paleozoic carbonate detritus.

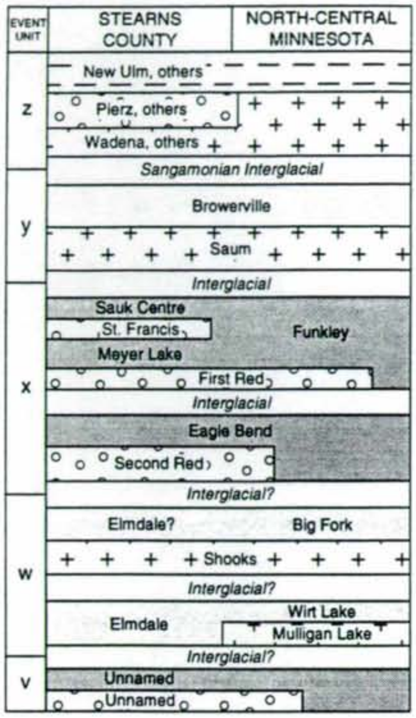
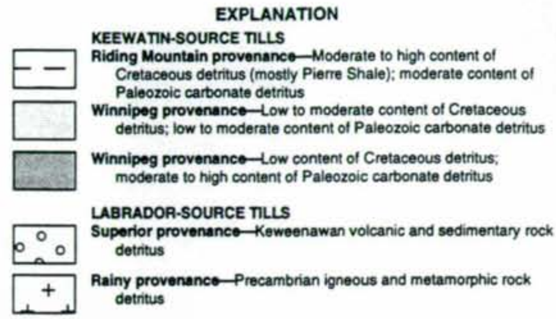


Figure 2. Stratigraphic placement of tills in Stearns County and north-central Minnesota. Modified from Meyer and Knaeble (1996).



Ice from the Labrador sector also crossed into Minnesota from two distinct source areas: the Rainy provenance to the north and northeast and the Superior provenance to the east and northeast. Tills of Rainy provenance are characterized by Archean igneous and metamorphic detritus, whereas tills of Superior provenance are rich in Mesoproterozoic volcanic and sedimentary detritus.

LOCAL STRATIGRAPHIC SETTING

Meyer and Knaeble (1996) identified in Stearns County a stratigraphic sequence of 15 till units attributable to the four described provenances. They divided that sequence into five unconformity-bounded groups labeled from V at the base to Z at the top (Fig. 2). The oldest Pleistocene materials in Stearns County are two unnamed tills assigned to unit V. They are preserved only in several deeply buried valleys in the southwestern corner of the county and have not been studied in detail. A hiatus of unknown duration separates unit V from the deposition of overlying strata assigned to unit W; unit W consists of the Elmdale (Winnipeg) and Shooks (Rainy) tills. The Elmdale constitutes the basal till across much of Stearns County; it is characterized by a small to moderate quantity of Paleozoic carbonate detritus. On a local scale, rock types and textures within the Elmdale can be closely associated with the underlying bedrock (Meyer and Knaeble, 1996). The overlying Shooks till contains detritus typical of an Archean terrain found in northern and north-central Minnesota, which consists of extremely weathered igneous and metamorphic rocks (Setterholm, 1996).

Several interlayered tills of Winnipeg and Superior provenance were deposited after a second hiatus that was probably related to an interglacial period. Tills assigned to unit X (Fig. 2) include the Second Red (Superior), Eagle Bend (Winnipeg), First Red (Superior), Meyer Lake (Winnipeg), St. Francis (Superior), and Sauk Centre (Winnipeg) tills. Neither the Second Red (Superior) till nor the clayey, carbonate-rich Eagle Bend (Winnipeg) till is widespread in Stearns County; consequently, they are not particularly well described. The Eagle Bend has been considerably eroded in places and is topped by a thick weathered zone that probably indicates a relatively long period of erosion and chemical weathering before deposition of the First Red till.

Owing to broadly similar lithic attributes, it is not possible to distinguish the Second Red till from the First Red till or from the St. Francis till without the presence of intervening Winnipeg-provenance tills such as the Meyer Lake, Eagle Bend, or Sauk Centre. The Sauk Centre and Meyer Lake tills also have broadly similar lithic attributes and can be easily distinguished as individual entities only where they are separated by the intervening St. Francis till.

A pronounced unconformity separates the Sauk Centre till from overlying tills assigned to unit Y. These overlying Saum (Rainy provenance) and Browerville (Winnipeg provenance) tills are separated by organic deposits that suggest a short hiatus between glacial advances. Both tills have been extensively eroded, and it is difficult to distinguish the Saum till from the overlying Wadena (Rainy) till of unit Z where the Browerville has been completely removed.

Unit Z, the youngest unit in Stearns County, contains the Wadena (Rainy), Pierz (Superior), and New Ulm (Riding Mountain) tills. An erosional unconformity separates the Wadena and Pierz tills, which is particularly evident in the eastern part of the county. The New Ulm Till is the youngest glacial deposit in Stearns County and, uniquely, contains a large detrital component of gray siliceous shale derived from the Pierre Shale of Late Cretaceous age in North Dakota. Consequently, the New Ulm Till is readily distinguished from the older till sheets.

PETROGRAPHY

Petrographic attributes of the till units in Stearns County include percentage and composition of rock fragments, sand composition, and texture (Meyer and Knaeble, 1996). Average values for matrix textures as summarized in Figure 3 are extracted from data in Table 3.2 of Meyer and Knaeble (1996). Although the Rainy and Superior tills contain on average more sand-size material than Winnipeg- or Riding Mountain–provenance tills, Figure 3 shows that grain size alone is not a useful attribute in distinguishing provenance or in recognizing individual till units.

Average values of lithic attributes represented in the 1–2-millimeter sand-size fraction are summarized in Figure 4 (data drawn from Table 3.3 of Meyer and Knaeble, 1996). All of the till units are characterized by nonunique quantities of admixed rock fragments of Precambrian (mainly igneous and metamorphic rocks, and sandstone) (Fig. 5), Paleozoic (mainly carbonate), and Cretaceous (mainly shale and carbonate) age (Fig. 6). Consequently, defining and correlating individual tills using the criterion of rock type is difficult, especially where large vertical and horizontal distances between sample sites are involved. Nonetheless, combined proportions of Precambrian and Paleozoic rock types in the sand-size fraction can be used to distinguish tills of Rainy and Superior provenances from those of Riding Mountain and Winnipeg provenances (Fig. 4). The data also show that tills of Winnipeg provenance can be divided into two subunits: one with a low content of carbonate (16–31 percent) and one with a high content of carbonate (33–43 percent). The low-carbonate till contains more Cretaceous rock fragments (7–8 percent vs. 1–3 percent) and quartz grains (41–42 percent vs. 16–33 percent), and a smaller proportion of granitic rock fragments (44–45 percent vs. 47–67 percent) than the high-carbonate till.

GEOCHEMICAL ATTRIBUTES

It is unlikely given the broadly similar stratigraphic and petrographic characteristics of the tills that geochemical data derived from these materials would provide an unambiguous means of differentiating them in Stearns County. The single example of a unique geochemical signature is found in the basal Elmdale till, which presents elevated values of iron, arsenic, cobalt, chromium, antimony, uranium, thorium, and zinc. The basal Elmdale also is marked by low sodium and calcium values relative to the other tills. Cores of the Elmdale till from drill holes SR-3 and SR-5 contain in places material similar to that found in underlying weathered bedrock. These results are consistent with the observations of Martin and others (1991), who suggest that arsenic and

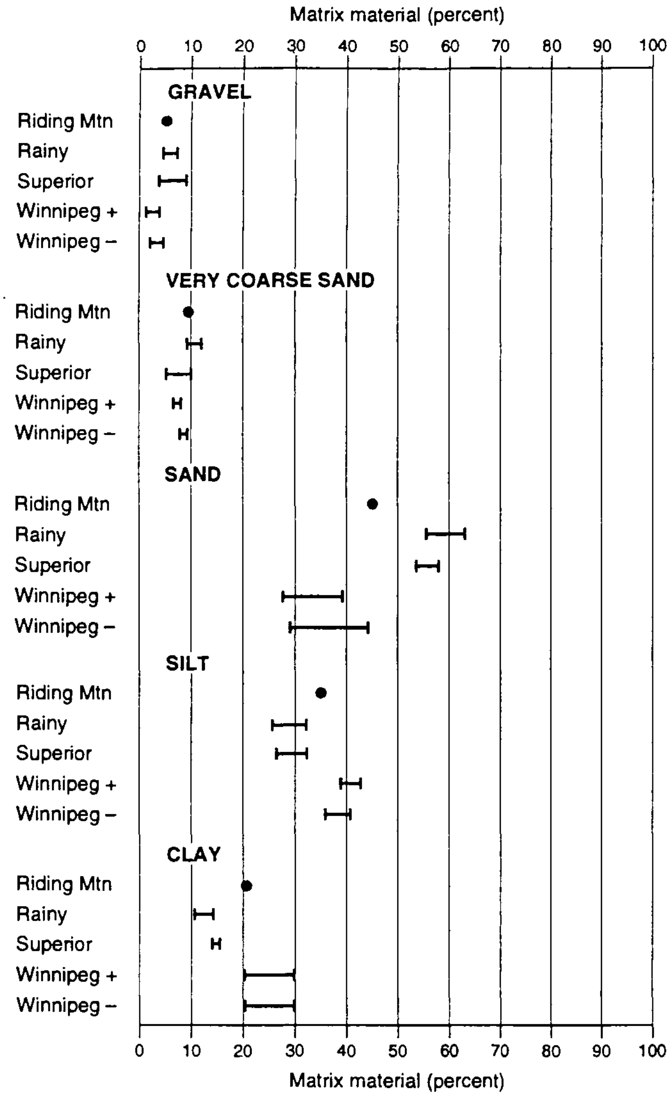


Figure 3. Average values for matrix components of tills of different provenances recognized in outcrop and in the subsurface, Stearns County, Minnesota. Based on data summarized from Table 3.2 of Meyer and Knaeble (1996).

EXPLANATION

● One sample (a single value)

Winnipeg + Winnipeg-provenance till with a high content of carbonate (33–43 percent)

Winnipeg - Winnipeg-provenance till with a low content of carbonate (16–31 percent)

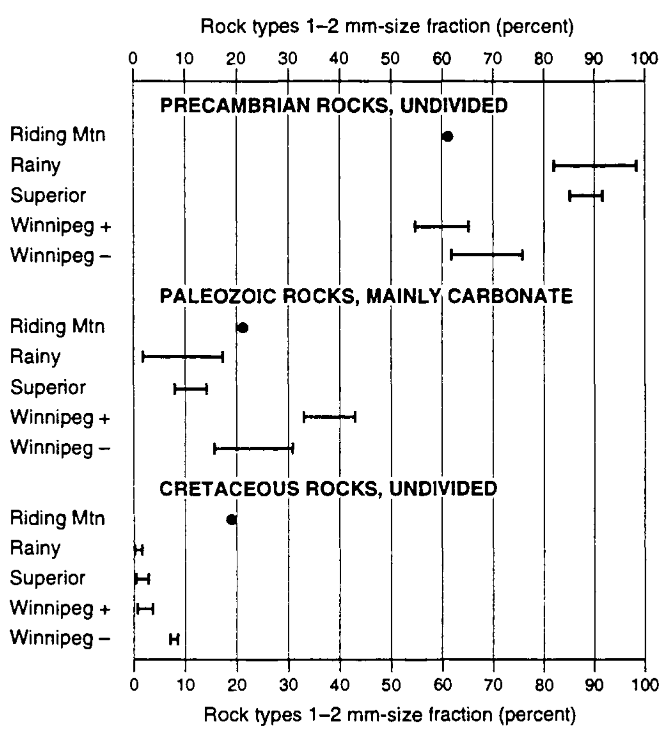


Figure 4. Average values of rock types in the 1-2-millimeter-size fraction of tills of different provenances recognized in outcrop and in the subsurface, Stearns County, Minnesota. Based on data summarized from Table 3.3 of Meyer and Knaeble (1996).

EXPLANATION

● One sample (a single value)

Winnipeg + Winnipeg-provenance till with a high content of carbonate (33–43 percent)

Winnipeg - Winnipeg-provenance till with a low content of carbonate (16–31 percent)

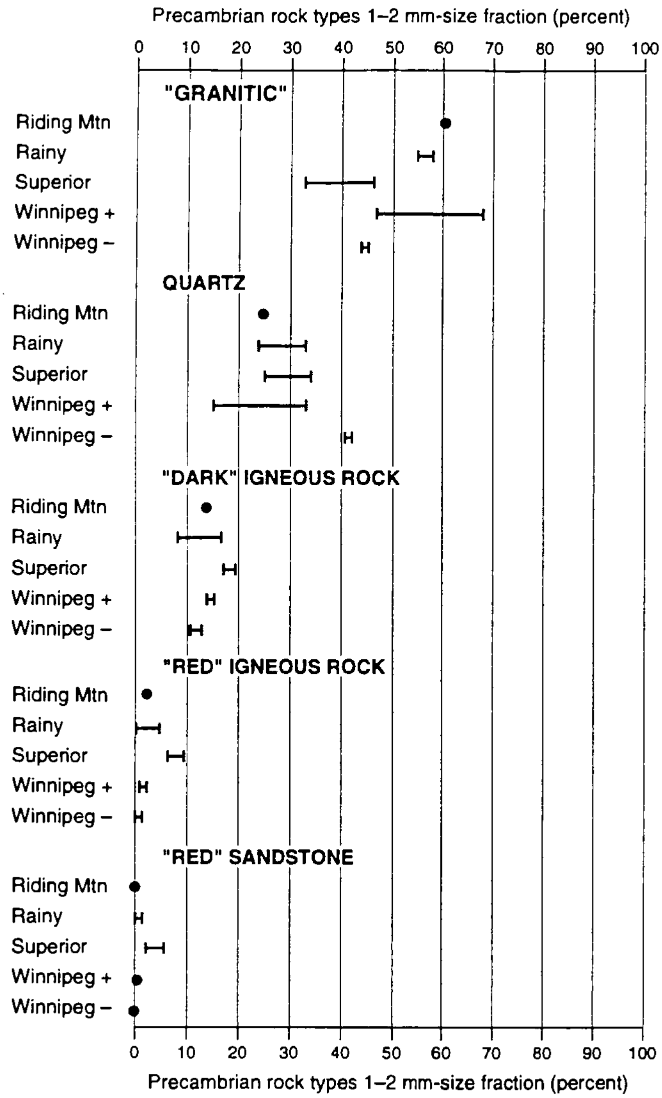


Figure 5. Average values of Precambrian rock types in the 1-2-millimeter-size fraction of tills of different provenances recognized in outcrop and in the subsurface, Stearns County, Minnesota. Based on data summarized from Table 3.3 of Meyer and Knaeble (1996).

EXPLANATION

● One sample (a single value)

Winnipeg + Winnipeg-provenance till with a high content of carbonate (33–43 percent)

Winnipeg - Winnipeg-provenance till with a low content of carbonate (16–31 percent)

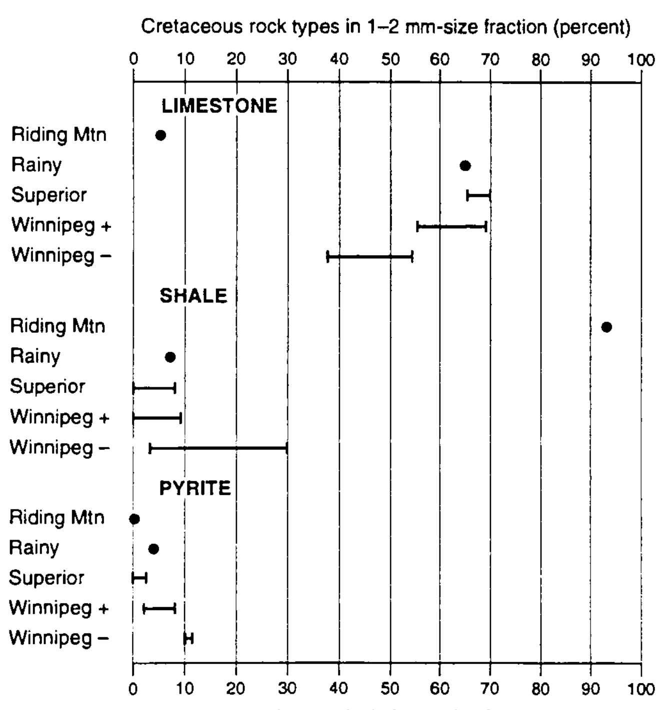


Figure 6. Average values for selected Cretaceous detritus in the 1–2-millimeter-size fraction of tills of different provenances recognized in outcrop and in the subsurface, Stearns County, Minnesota. Based on data summarized from Table 3.3 of Meyer and Knaeble (1996).

EXPLANATION

● One sample (a single value)

Winnipeg + Winnipeg-provenance till with a high content of carbonate (33–43 percent)

Winnipeg - Winnipeg-provenance till with a low content of carbonate (16–31 percent)

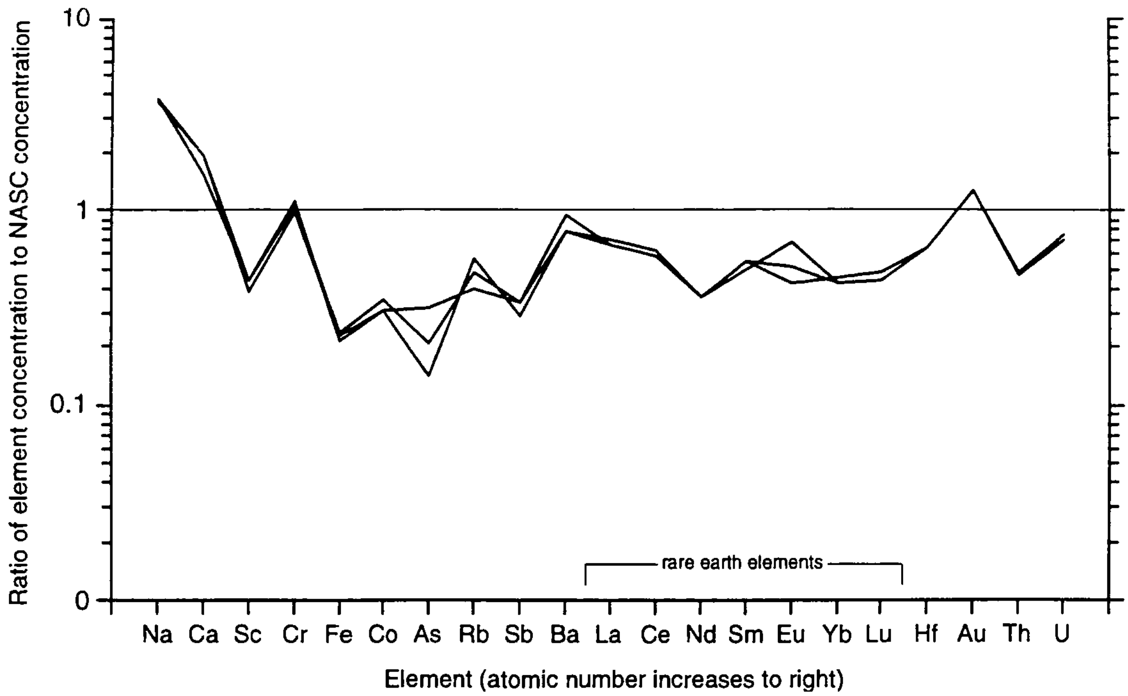


Figure 7. Line diagram summarizing elemental abundances, relative to NASC (Table 2), of tills derived from the Riding Mountain provenance.

zinc among other constituents tended to have higher values in basal Winnipeg-provenance tills of northern Minnesota.

Elements in tills younger than the Elmdale have broadly similar enrichment patterns, which probably reflect that mixing occurred as younger ice sheets passed over and incorporated older deposits. Thus, if tills of several provenances once had unique geochemical signatures, those signatures were attenuated as the tills were mixed to the point where there is little unique basis for identification, even over relatively short distances. The broadly similar geochemical signatures are shown in Figures 7, 8, 9, 10, and 11. For comparative purposes, the elemental data tabulated in Appendix Table A-1 were normalized against the standard values of the North American Shale Composite (NASC) (Table 2) as summarized by Gromet and others (1984). The data show that although it is not possible to identify individual tills, it is possible to recognize geochemical signatures that can be attributed to the major provenances.

Till derived from the Riding Mountain provenance is distinguished petrographically by an appreciable amount of detritus from the Upper Cretaceous Pierre Shale. Nonetheless, the New Ulm till contains on average as much as 80 percent Precambrian and Paleozoic detritus. In consequence, the till is characterized by a mixed geochemical signature greatly enriched in sodium and calcium, and modestly enriched in chromium and gold (Fig. 7). Other element data (non-rare earth) are significantly depleted relative to the NASC standard.

Rare-earth-element patterns associated with the Riding Mountain provenance are similar to patterns associated with Cretaceous rocks. However, the content of Riding Mountain–provenance tills (Fig. 7) are significantly depleted relative to the NASC standard and to the majority of Cretaceous samples analyzed in this study (Fig. 8). It is interesting to speculate whether the Cretaceous source of the Riding Mountain till is also depleted in rare earth elements relative to the Cretaceous rocks sampled in this study.

Table 2. Reported elemental values for the North American Shale Composite (NASC).
[From Gromet and others, 1984]

Value	Element		Unit of measure	Value	Element		Unit of measure
8.8	Ca	Calcium	percent	27.4	*Nd	Neodymiun	parts per million
4	Fe	Iron	percent	58	Ni	Nickel	parts per million
				125	Rb	Rubidium	parts per million
28.4	As	Arsenic	parts per million	2.09	Sb	Antimony	parts per million
636	Ba	Barium	parts per million	14.9	Sc	Scandium	parts per million
0.69	Br	Bromine	parts per million	5.59	*Sm	Samarium	parts per million
66.7	*Ce	Cerium	parts per million	142	Sr	Strontium	parts per million
25.7	Co	Cobalt	parts per million	1.12	Ta	Tantalum	parts per million
124.5	Cr	Chromium	parts per million	0.85	*Tb	Terbium	parts per million
5.16	Cs	Cesium	parts per million	12.3	Th	Thorium	parts per million
1.18	*Eu	Europium	parts per million	2.66	U	Uranium	parts per million
6.3	Hf	Hafnium	parts per million	2.1	W	Tungsten	parts per million
31.1	*La	Lanthanum	parts per million	3.06	*Yb	Ytterbium	parts per million
0.456	*Lu	Lutetium	parts per million	70	Zn	Zinc	parts per million
0.85	Na	Sodium	parts per million				

*Rare earth element

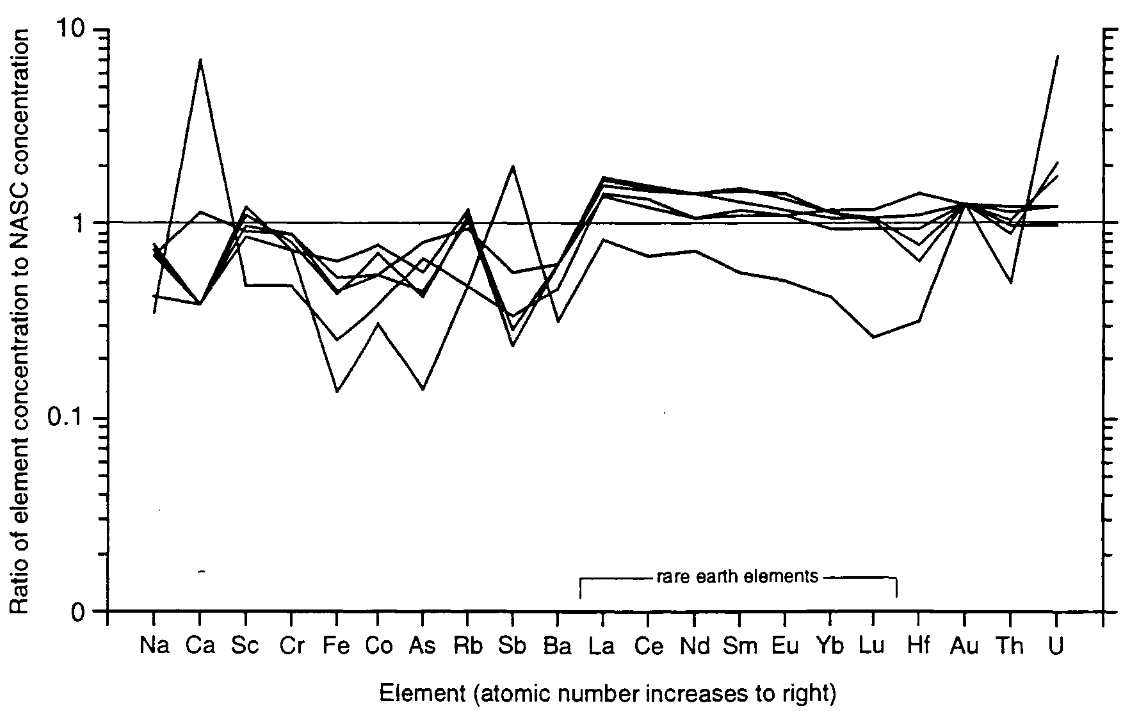


Figure 8. Line diagram summarizing elemental abundances, relative to NASC (Table 2), of Cretaceous strata in the subsurface of Stearns County (Setterholm, 1996).

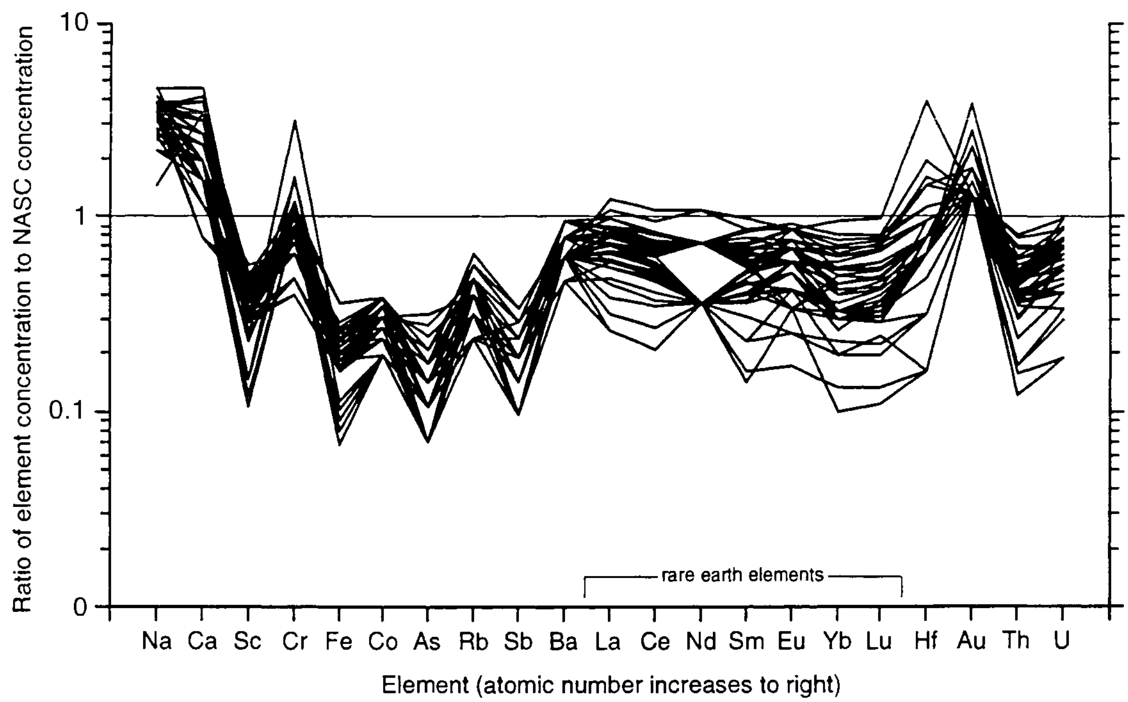


Figure 9. Line diagram summarizing elemental abundances, relative to NASC (Table 2), of tills derived from the Winnipeg (high carbonate) provenance.

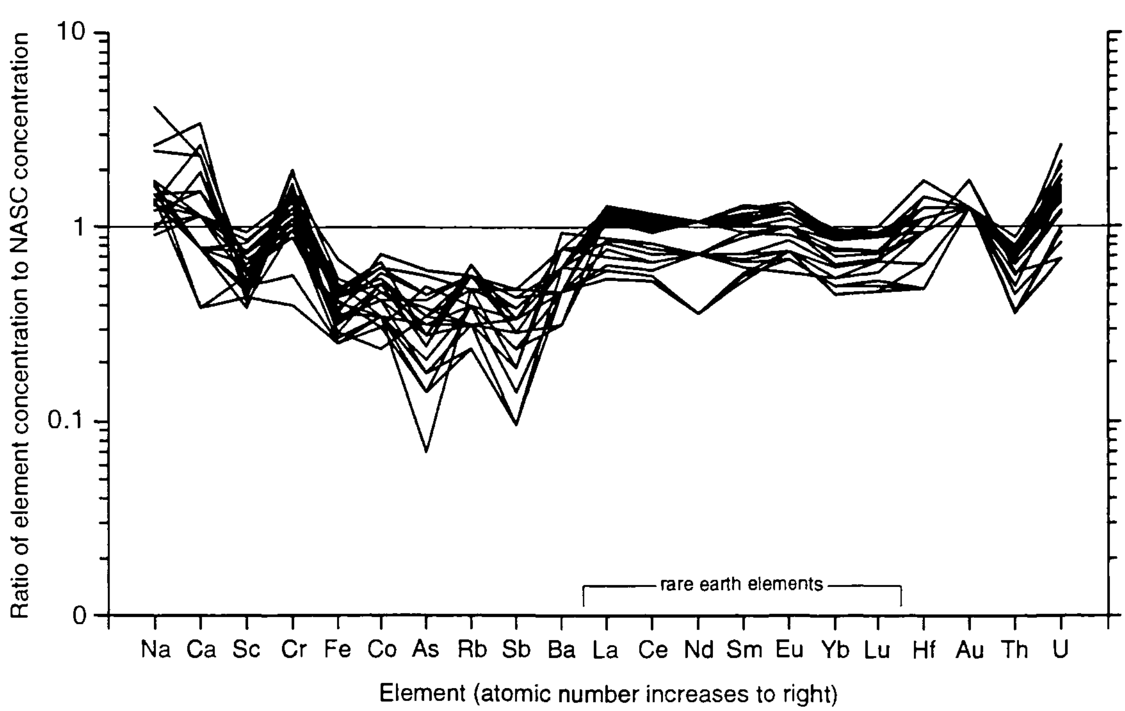


Figure 10. Line diagram summarizing elemental abundances, relative to NASC (Table 2), of tills derived from the Winnipeg (low carbonate) provenance.

Tills of Winnipeg provenance are divided into two subsets on the basis of their relative content of carbonate detritus (Figs. 9 and 10). Not surprisingly, high-carbonate tills contain significantly more calcium and more sodium than do the low-carbonate tills. The high-carbonate tills generally have similar or slightly lower concentrations of other elements relative to the low-carbonate tills.

Both subsets have flat rare-earth-element signatures that are characterized by neutral to slightly negative cerium anomalies and slightly to moderately positive europium anomalies. Rare-earth-element values from the high-carbonate tills are more variable than values for low-carbonate tills. High-carbonate tills are also depleted in rare earth elements relative to those of the low-carbonate subset. The values for the low-carbonate till samples are very similar to those of the saprolith (Fig. 11), the presumed closest source material for these basal till units.

Tills attributed to the Rainy provenance contain appreciable Precambrian crystalline and Paleozoic carbonate detritus but very little Cretaceous detritus. The 1–2-millimeter sand fraction in one sample (drill hole SR-3; 41.5 ft) contains approximately 90 percent Precambrian crystalline detritus. The Rainy tills have pronounced sodium and calcium anomalies (Fig. 12) that are similar to those associated with the high-carbonate tills of Winnipeg provenance (Fig. 9) and tills of Superior provenance (Fig. 13). Other non–rare earth elements, except chromium and gold, are depleted relative to the NASC. On the basis of the limited sampling, it is not possible to determine if the observed gold values reflect a nugget effect or fine gold disseminated throughout the matrix of these tills.

The rare-earth-element values in the Rainy tills are somewhat depleted relative to NASC and have light to heavy rare-earth-element ratios of near one. However, 10 of 13 samples have moderately positive europium anomalies and flat to vaguely positive cerium anomalies. One sample from the uppermost part of the Wadena till (drill hole SR-3; 19.5 ft) consists dominantly of carbonate

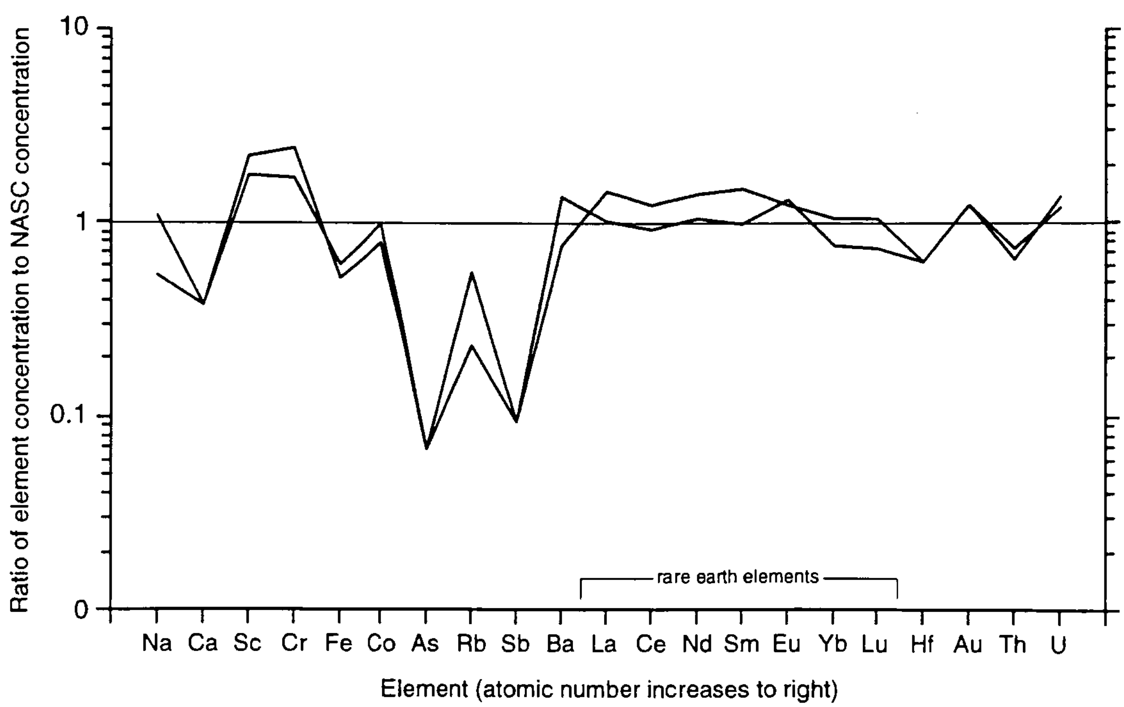


Figure 11. Line diagram summarizing average elemental abundances of saprolith, relative to NASC (Table 2), associated with a period of pre-Cretaceous weathering of the Paleoproterozoic Little Falls Formation in Stearns County (Boerboom, 1996).

detritus, and it has a signature marked by elevated rare earth elements and the absence of a europium anomaly. As such, it resembles rare-earth-element signatures associated with tills of the Winnipeg provenance (Figs. 9 and 10).

Tills derived from the Superior provenance are mainly distinguished from Rainy tills by the amount of sandstone and red detritus they contain (see Table 3.3 in Meyer and Knaeble, 1996). Consequently, Rainy and Superior tills have broadly similar geochemical signatures (Fig. 14). Given the presumed red-bed sedimentary source for the Superior-provenance tills, it is somewhat surprising that some samples are generally enriched in gold relative to NASC (Table 2).

The rare-earth-element signatures from Superior tills are strongly depleted in total rare earth elements relative to NASC. All samples have light to heavy rare-earth-element ratios of approximately one. Fourteen of 16 samples have moderately to strongly positive europium anomalies, and 8 of 16 samples have slightly negative cerium anomalies. However, one sample of St. Francis till (drill hole SR-3, 67.5 ft) is quite clayey; it contains appreciably more of the total rare earth elements and a pronounced europium anomaly.

DISCUSSION

Cretaceous rocks in Stearns County largely consist of weathered clayey sandstone, carbonaceous siltstone, and silty rocks (Setterholm, 1996). The sediments that form the silty and shaly rocks were deposited in a broadly reducing environment; the rocks contain pyrite as balls or burrow fillings and are generally noncalcareous except for rare concretions of siderite.

Patterns of non–rare earth elements associated with the Cretaceous rocks (Fig. 8) are similar to or are somewhat depleted relative to the NASC standard. Rare-earth-element signatures are generally flat to slightly enriched in the light rare earth elements. Two samples were characterized by slightly negative cerium and moderately positive samarium anomalies. One sample has a slightly positive europium anomaly.

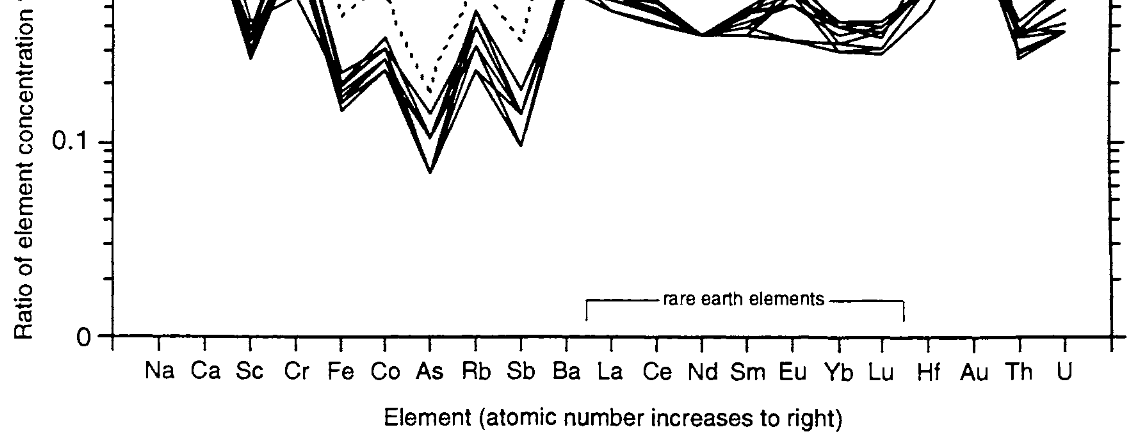


Figure 12. Line diagram summarizing elemental abundances, relative to NASC (Table 2), of tills derived from the Rainy provenance.

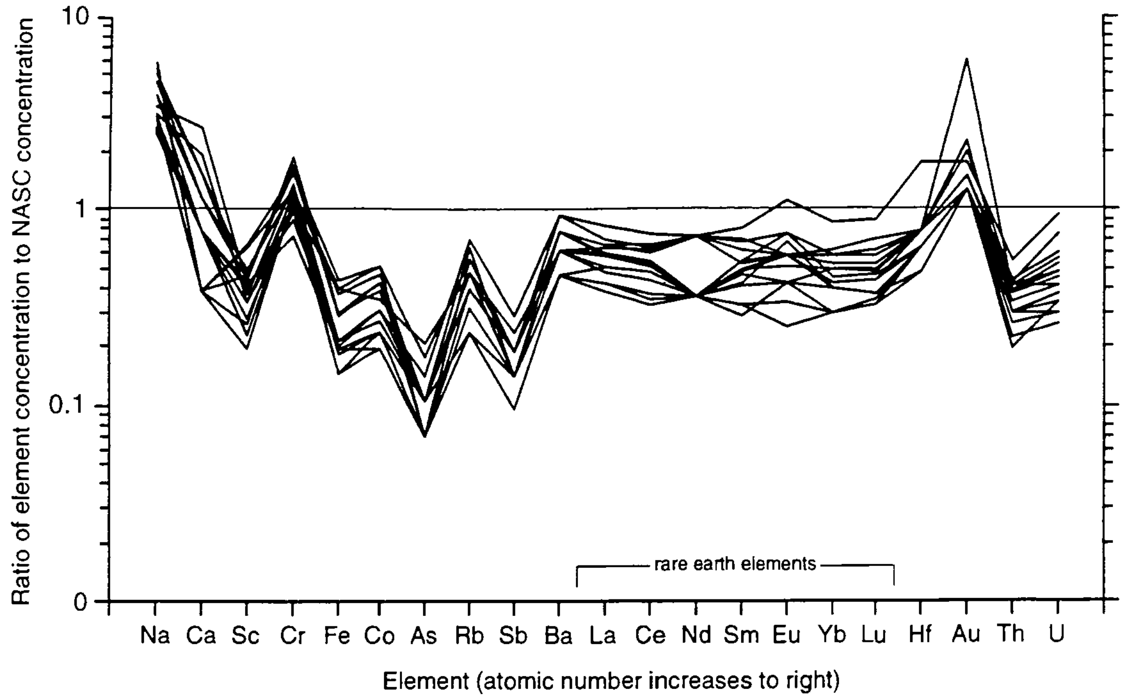


Figure 13. Line diagram summarizing elemental abundances, relative to NASC (Table 2), of tills derived from the Superior provenance.

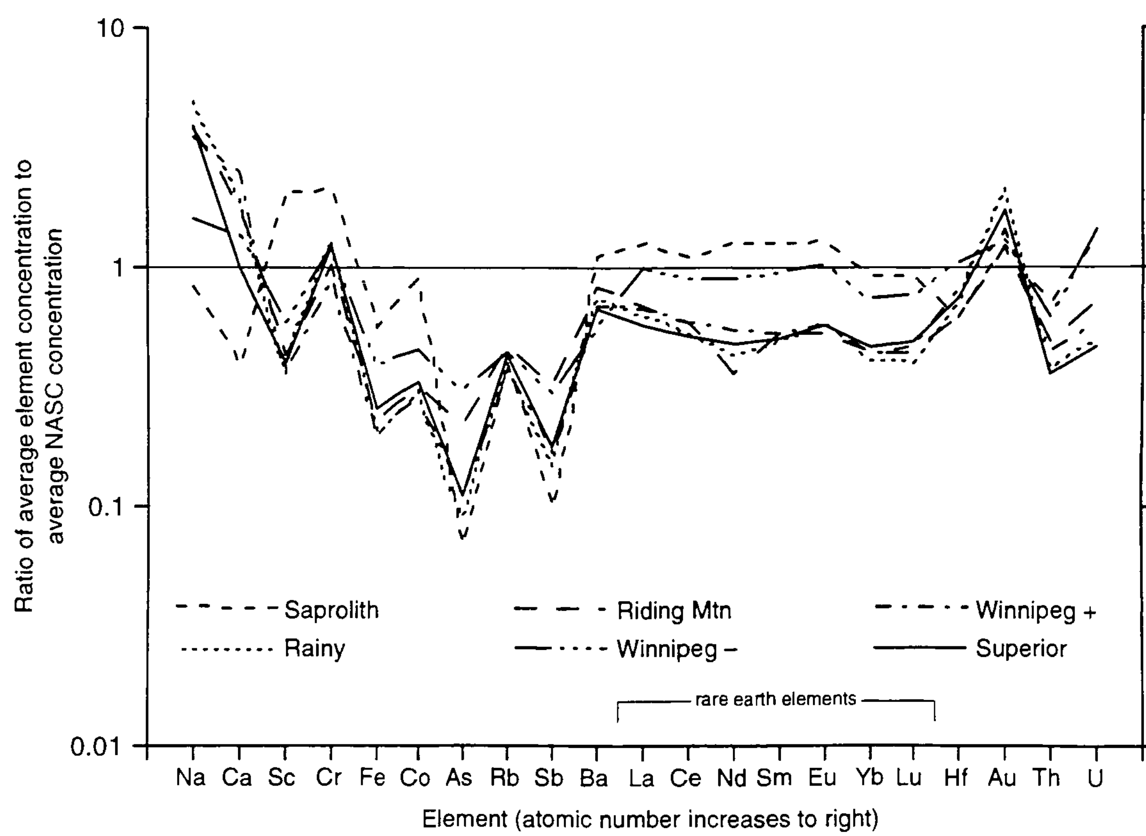


Figure 14. Line diagram summarizing average elemental abundances of all till samples relative to NASC (Table 2). Winnipeg -, Winnipeg-provenance till with low content of carbonate (16–31 percent); Winnipeg +, Winnipeg-provenance till with high carbonate content (33–43 percent).

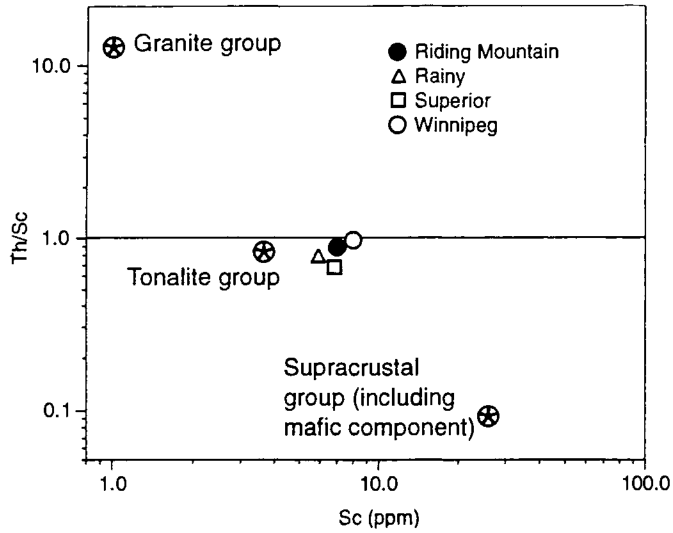


Figure 15. Thorium/scandium vs. scandium plot for samples of various till provenances represented in Stearns County. Also included are the end-member components from the Archean Superior provenance (granite group, tonalite group and supracrustal group) (Fedo and others, 1997). Note that the average till values tend to plot along the join between the "granite" end member and the "supracrustal" end member.

Saprolith (Fig. 11) at the bedrock surface and incorporated into overlying till in drill holes SR-3 and SR-5 was derived by the in-situ weathering of the Little Falls Formation, a staurolite schist of Paleoproterozoic age. The saprolith is enriched in scandium, chromium, iron, cobalt, and uranium but depleted in arsenic, rubidium, antimony, and thorium relative to the NASC standard (Table 2) and other samples. These attributes are characteristic of development in an overall oxidizing environment.

CONCLUSIONS

Petrographic studies summarized by Meyer and Knaeble (1996) show that various till units in the subsurface of Stearns County contain detritus derived from Precambrian, Paleozoic, and Cretaceous sources. They used the relative proportions of this detritus, as well as color and texture, to recognize and relate till units to particular provenances.

Previous attempts in Minnesota to characterize and trace individual till units using minor- and trace-elemental data have met with limited success. Our results are no exception. The lack of substantial differences among the elemental data reported here confirms the view that considerable reworking and homogenization occurred as succeeding generations of glacial ice scraped across the surface of the state.

Summary results illustrated in Figure 14 show that there is very little to distinguish till units derived from the three principal source areas. Tills of the Winnipeg provenance (low-carbonate till) stand out somewhat by virtue of higher rare-earth-element contents and lower sodium values. In as much as composite elemental profiles are not unique to any individual unit, lithologic and other kinds of field criteria are still needed to characterize a specific till unit.

On a broader scale, thorium/scandium vs. scandium values for the four identified glacial provenances are plotted together with values from three potential end members in the basement rock of the Archean Superior provenance in Figure 15. The average values for the glacial materials lie along the join between a "granite" end member and a "supracrustal" end member, suggesting that regardless of subsequent geologic history the individual till units are simply mechanical mixtures of material derived from the Superior provenance of the Canadian Shield (Fedo and others, 1997).

We suggest that geochemical attributes, like petrographic attributes, are by themselves insufficient to distinguish individual till units where extensive mixing and homogenization have occurred. We recognize that it is entirely possible that other sets of geochemical data may be more robust when derived from an environment in which mixing has not been as prevalent. Nonetheless, obvious questions remain as to which approach—petrographic or geochemical—is more efficient and, consequently, cost-effective in stratigraphic analyses. The use of geochemical attributes can be advanced by the continued use of very carefully selected samples for which petrographic and geochemical results can be correlated on a one-to-one basis. Additionally, should such analyses be done, we recommend that future geochemical studies of Pleistocene materials be accomplished entirely by Instrumental Neutron Activation Analysis methods. Lastly, we recommend that standard samples be developed for tills in Minnesota for use in comparing and evaluating the analytical methods now in use. This would permit better interpretation of results within individual data sets and allow more reliable correlation among data sets collected throughout the state.

APPENDIX

Table A-1, which begins on the following page, is a summary table of all the geochemical analyses performed as part of this study. The samples were collected from five drill holes as part of the preparation of the geologic atlas of Stearns County, Minnesota (Meyer, 1995). The analytical technique used is Instrumental Neutron Activation Analysis (INAA). XRAL Activation Services Inc., of Ann Arbor, Michigan, analyzed 123 subsurface samples from five drill holes for 32 elements. Refer to Figure 1 for the location of the drill holes. For reference, detection limits and reported elemental values for the North American Shale Composite (NASC) are given below.

Element detection limits for Appendix Table A-1.

Element		Detection Limit	Element		Detection Limit
Ca	Calcium	1 percent	Mo	Molybdenum	5 parts per million
Fe	Iron	0.0 percent	Na	Sodium	500 parts per million
			*Nd	Neodymium	10 parts per million
Au	Gold	5 parts per billion	Ni	Nickel	100 parts per million
Ir	Iridium	20 parts per billion	Rb	Rubidium	30 parts per million
Ag	Silver	5 parts per million	Sb	Antimony	0.0 parts per million
As	Arsenic	2 parts per million	Sc	Scandium	0.0 parts per million
Ba	Barium	100 parts per million	Se	Selenium	5 parts per million
Br	Bromine	1 part per million	*Sm	Samarium	1 parts per million
*Ce	Cerium	3 parts per million	Sr	Strontium	500 parts per million
Co	Cobalt	5 parts per million	Ta	Tantalum	1 parts per million
Cr	Chromium	10 parts per million	*Tb	Terbium	1 parts per million
Cs	Cesium	3 parts per million	Th	Thorium	1 parts per million
*Eu	Europium	0.0 parts per million	U	Uranium	1 parts per million
Hf	Hafnium	1 parts per million	W	Tungsten	4 parts per million
*La	Lanthanum	1 parts per million	*Yb	Ytterbium	0.0 parts per million
*Lu	Lutetium	0.0 parts per million	Zn	Zinc	50 parts per million

*Rare earth element

Reported elemental values for the North American Shale Composite (NASC).

[From Gromet and others, 1984]

Value	Element	Unit of measure	Value	Element	Unit of measure
8.8	Ca	percent	27.4	*Nd	parts per million
4	Fe	percent	58	Ni	parts per million
			125	Rb	parts per million
28.4	As	parts per million	2.09	Sb	parts per million
636	Ba	parts per million	14.9	Sc	parts per million
0.69	Br	parts per million	5.59	*Sm	parts per million
66.7	*Ce	parts per million	142	Sr	parts per million
25.7	Co	parts per million	1.12	Ta	parts per million
124.5	Cr	parts per million	0.85	*Tb	parts per million
5.16	Cs	parts per million	12.3	Th	parts per million
1.18	*Eu	parts per million	2.66	U	parts per million
6.3	Hf	parts per million	2.1	W	parts per million
31.1	*La	parts per million	3.06	*Yb	parts per million
0.456	*Lu	parts per million	70	Zn	parts per million
0.85	Na	parts per million			

*Rare earth element

Table A-1. Elemental geochemistry of selected till samples from the surface and subsurface of Stearns County, Minnesota

[Refer to page 15 for analytical technique, elemental detection limits, and reported elemental values for the North American Shale Composite (NASC). Symbols: -, less than; K, Cretaceous; BR, Browerville; EB, Eagle Bend; ED, Elmdale; FR, First Red; ML, Meyer Lake; NU, New Ulm; Pz, Pierz; SC, Sauk Centre; SF, St. Francis; SK, Shooks; SM, Saum; WD, Wadena; PC, Precambrian]

Hole		SR-1		SR-2					SR-3				
Unit	K	K	K	BR	PZ	PZ	PZ	PZ	PZ	WD	WD	WD	WD
Depth (ft)	23	69	131	3	1	5	9	15	17	19.5	23	26.5	30
Elements in percent													
Ca	1	1	-1	6	1	-1	4	-1	4	9	4	5	5
Fe	3.9	5.6	1.2	2	2.5	3.8	1.9	3.5	2.6	4	2	1.8	1.8
Elements in parts per billion													
Au	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
Ir	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
Elements in parts per million													
Ag	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
As	12	16	4	6	3	5	3	2	3	5	2	4	3
Ba	400	400	300	400	500	600	500	500	500	1100	400	400	400
Br	2	2	2	3	2	2	2	1	2	4	2	2	2
Ce	103	106	89	45	35	43	35	44	36	83	35	32	35
Co	18	20	8	8	11	13	7	13	10	16	8	8	9
Cr	100	90	90	170	200	190	170	160	210	330	200	210	200
Cs	8	8	4	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
Eu	1.7	1.6	1.3	0.7	0.7	0.7	0.7	0.9	0.9	1.3	0.8	0.6	0.6
Hf	5	4	9	5	4	5	4	5	4	9	4	4	4
La	52	55	45	23	18	22	18	21	19	42	19	18	18
Lu	0.49	0.48	0.54	0.23	0.17	0.32	0.2	0.27	0.21	0.35	0.19	0.19	0.18
Mo	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
Na	1800	1900	1100	6900	14000	15000	12000	14000	13000	23000	11000	11000	11000
Nd	40	40	30	20	10	20	10	20	10	30	10	10	10
Ni	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100
Rb	140	150	60	50	80	70	60	70	60	90	60	50	60
Sb	0.6	0.5	0.7	0.5	0.3	0.4	0.3	0.4	0.4	0.7	0.4	0.3	0.3
Sc	16.4	18.3	12.8	5.8	7	9.9	5.5	9.6	7	11.8	5.8	5.2	5.2
Se	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
Sm	8.4	8.7	6.6	3.4	2.7	4	2.8	3.8	3.1	6.8	2.8	2.6	2.7
Sr	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500
Ta	-1	-1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Tb	0.9	1.1	0.8	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	0.7	-0.5	-0.5	-0.5
Th	14	15	13	6.4	5.1	5.1	5	4.6	4.2	9	5.2	4.6	4.7
U	3.3	3.3	4.6	3.4	1.3	1.5	1.1	1.2	1.1	2.4	1.7	1.7	1.6
W	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	14
Yb	3.5	3.5	3.6	1.5	1.2	1.9	1.3	1.8	1.4	2.7	1.3	1.2	1.1
Zn	80	60	-50	-50	-50	-50	-50	-50	-50	50	-50	-50	-50

Table A-1 *continued*. Elemental geochemistry of selected till samples from the surface and subsurface of Stearns County, Minnesota.

Hole	SR-3 continued																
Unit	BR	SM	SC	SC	SC	SC	SC	SC	SC	SC	SC	SC	SF	SF	SF	SF	SF
Depth	33.5	39	39	41.5	43.5	46.5	49.5	52.5	55.5	58	61	64	67.5	70	73.5	77	80.5
Elements in percent																	
Ca	6	9	6	7	11	10	10	9	9	3	6	2	2	2	2	2	5
Fe	2.2	2.2	2.2	1.7	1.6	1.4	1.4	1.4	1.6	2.3	1.4	1.6	1.8	1.3	1.7	3.5	1.9
Elements in parts per billion																	
Au	-5	-5	7	7	9	5	7	6	11	-5	-5	7	7	9	6	8	24
Ir	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
Elements in parts per million																	
Ag	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
As	14	6	2	-2	-2	-2	4	2	2	4	5	3	4	2	3	6	3
Ba	300	500	600	500	300	400	400	400	500	500	500	600	600	400	400	400	400
Br	3	4	2	2	3	3	3	2	3	1	2	1	1	1	1	2	3
Ce	44	49	52	37	35	31	31	34	34	55	46	48	51	32	37	41	34
Co	8	9	9	8	6	9	6	6	6	8	7	8	8	6	6	9	7
Cr	120	50	70	70	60	50	50	50	60	90	100	100	90	130	120	130	150
Cs	-3	-3	-3	-3	-3	-3	-3	-3	-3	3	-3	-3	-3	-3	-3	-3	-3
Eu	0.7	0.9	1	0.7	0.5	0.7	0.4	0.6	0.5	1.1	0.9	1	1.3	0.5	0.7	0.7	0.6
Hf	6	7	6	4	4	5	4	4	4	7	9	9	11	5	5	5	5
La	24	26	28	19	18	17	17	19	18	30	24	25	26	16	19	20	18
Lu	0.27	0.3	0.31	0.18	0.15	0.15	0.16	0.16	0.16	0.37	0.32	0.36	0.4	0.23	0.24	0.28	0.22
Mo	6	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
Na	6500	7000	11000	13000	9500	9500	10000	10000	10000	6700	7400	8500	10000	6600	7000	6400	8200
Nd	20	20	20	10	10	10	10	10	10	20	20	20	20	10	10	20	10
Ni	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100
Rb	50	50	60	50	30	50	60	50	50	70	60	60	90	50	60	60	50
Sb	0.5	0.7	0.4	0.3	0.2	0.2	0.2	0.2	0.3	0.7	0.5	0.6	0.6	0.4	0.5	0.4	0.4
Sc	6.1	6.5	7.5	6.4	4.4	4.4	4.3	4.6	4.7	7.1	5.7	6.1	6.3	4.1	5	6	5.1
Se	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
Sm	3.5	4.1	4.1	2.7	2.3	2.3	2.3	2.5	2.5	4.6	3.8	4.1	4.5	2.6	3.1	3.5	2.8
Sr	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500
Ta	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Tb	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	0.5	0.5	0.5	0.6	-0.5	-0.5	-0.5	-0.5
Th	6.2	6.9	7.2	4.7	4.6	4.4	4.4	4.9	4.7	8.4	5.8	6.6	6.7	3.7	4.7	5.2	4.7
U	4	3.2	1.8	1	1.1	1.1	1.1	1.1	1.2	1.8	1.8	1.7	2.5	1	1.3	2	1.4
W	-4	-4	-4	-4	-4	73	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
Yb	1.7	1.9	2	1.3	0.9	1	0.9	1	0.9	2.5	2.1	2.3	2.6	1.5	1.6	1.8	1.5
Zn	-50	50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50

Table A-1 *continued*. Elemental geochemistry of selected till samples from the surface and subsurface of Stearns County, Minnesota.

Hole	**SR-3** *continued*																
Unit	SF	ML	ML	ML	ML	ML	ML	ML	ML	ML	ML	EB	EB	ED	ED	ED	ED
Depth (ft)	84	87	91	95	99	103	106.5	113	119.5	126	132.5	136	141	145	149	152	156.5
Elements in percent																	
Ca	7	8	8	8	8	8	8	8	8	5	5	4	9	2	1	2	2
Fe	1.9	1.9	1.9	2	2.1	2.1	1.5	1.7	1.8	2.4	2.4	2.5	2.2	3.7	6	4	3.6
Elements in parts per billion																	
Au	6	-5	-5	15	6	9	9	-5	-5	-5	5	-5	7	-5	-5	-5	5
Ir	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
Elements in parts per million																	
Ag	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
As	3	2	2	2	4	4	2	4	3	3	9	5	2	4	11	10	9
Ba	500	500	400	400	400	500	400	400	400	400	500	500	400	400	500	400	400
Br	3	2	3	3	3	3	2	2	3	2	2	3	2	2	2	3	2
Ce	40	44	43	41	43	44	34	36	39	45	49	63	51	38	44	74	65
Co	8	8	9	10	9	9	6	7	8	10	8	10	10	8	12	14	9
Cr	110	110	110	100	100	110	100	100	120	120	110	80	90	190	200	150	160
Cs	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	4	3	-3	-3	3	-3
Eu	0.7	0.8	0.8	0.9	0.7	0.8	0.5	0.8	0.7	0.7	0.8	1	0.8	0.9	0.9	1.5	1.3
Hf	5	5	5	4	4	5	4	4	4	5	6	7	5	4	4	8	7
La	21	23	22	21	23	24	18	20	21	24	26	34	28	19	22	39	33
Lu	0.2	0.23	0.22	0.21	0.21	0.22	0.19	0.18	0.19	0.27	0.3	0.34	0.27	0.21	0.3	0.43	0.4
Mo	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	5
Na	8800	9300	9400	9600	9100	9000	9300	9600	9600	6500	5700	5700	3700	4400	4600	3500	3900
Nd	20	20	20	10	20	20	10	10	10	20	20	30	20	10	20	30	30
Ni	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100
Rb	50	50	60	60	40	60	50	50	50	60	50	80	60	30	40	70	50
Sb	0.4	0.3	0.3	0.4	0.4	0.4	0.3	0.3	0.3	0.4	0.4	0.7	0.5	0.2	0.4	0.8	0.7
Sc	6.1	6.5	6.4	6.4	6.7	6.9	4.8	5.5	5.6	7	6.9	8.3	7.7	5.8	8.3	11.4	9.6
Se	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
Sm	3	3.3	3.2	3	3.1	3.5	2.5	2.7	2.9	3.6	3.9	4.8	3.9	3.3	3.8	6.7	5.7
Sr	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500
Ta	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Tb	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	0.5	-0.5	-0.5	-0.5	0.8	0.7
Th	5.3	6.3	5.8	5.5	5.6	6.3	4.6	4.6	5.4	6.4	6.6	9.7	7.6	4.6	5.6	9.9	8.4
U	1.6	1.6	1.8	1.7	1.8	2.1	1.4	1.5	1.8	1.9	2	2.3	2.4	1.8	2.2	4.4	4.1
W	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
Yb	1.3	1.4	1.5	1.2	1.2	1.5	1.1	1	1.2	1.7	1.9	2.2	1.6	1.4	1.7	3	2.6
Zn	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	60	80	-50

Table A-1 *continued.* Elemental geochemistry of selected till samples from the surface and subsurface of Stearns County, Minnesota.

Hole	SR-3 *continued*								SR-4				SR-5			
Unit	ED	ED	ED	ED	ED	ED	ED	PC	SC	ML	SK	ED	NU	NU	NU	WD
Depth (ft)	161	165.5	170	173	176.5	180	182.5	187	20	27	34	39	2	5.5	9	13
Elements in percent																
Ca	3	2	3	2	2	2	3	-1	8	7	3	2	5	4	5	4
Fe	4.1	39	4	4.5	4.8	3.2	4.2	4.7	1.6	1.5	2	3.4	2.1	1.9	2	1.6
Elements in parts per billion																
Au	-5	-5	-5	-5	-5	-5	7	-5	-5	-5	-5	-5	-5	-5	-5	-5
Ir	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
Elements in parts per million																
Ag	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
As	13	7	8	5	5	4	8	-2	2	2	-2	5	6	4	9	3
Ba	300	400	400	300	300	300	300	500	500	400	700	600	600	500	500	400
Br	4	2	3	1	2	2	3	-1	2	2	2	2	2	2	2	2
Ce	71	79	66	38	35	40	68	85	34	35	63	101	39	42	39	33
Co	16	13	14	9	11	9	17	21	7	7	7	10	9	8	8	7
Cr	160	170	170	190	240	250	180	310	100	40	150	150	130	140	120	140
Cs	3	3	4	-3	-3	-3	4	-3	-3	-3	-3	-3	3	3	-3	-3
Eu	1.5	1.5	1.5	0.8	0.9	0.8	1.2	1.5	0.6	0.6	0.8	1.4	0.5	0.6	0.8	0.9
Hf	7	8	7	3	3	3	6	4	4	4	5	7	4	4	4	6
La	37	41	35	19	17	20	36	47	18	18	34	55	21	22	21	18
Lu	0.43	0.43	0.4	0.23	0.21	0.24	0.41	0.5	0.13	0.14	0.15	0.32	0.22	0.2	0.2	0.16
Mo	6	-5	-5	-5	-5	-5	6	-5	-5	-5	-5	-5	-5	-5	-5	-5
Na	3800	4400	4500	4200	4300	4400	3400	1400	9900	14000	12000	5000	9700	9900	9600	13000
Nd	30	30	30	10	10	20	30	40	10	10	20	40	10	10	10	10
Ni	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100
Rb	70	80	80	40	30	50	70	-30	50	40	60	80	60	70	50	50
Sb	0.7	0.6	0.7	0.2	0.2	0.3	0.7	-0.2	0.3	0.2	0.2	0.4	0.7	0.6	0.7	0.3
Sc	11.3	12.4	13	7.2	6.9	7.4	14	34.2	4.6	5	5.2	7.5	6.6	6.6	5.8	5
Se	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
Sm	6.3	7.4	5.9	3.2	3	3.7	5.8	8.5	2.5	2.5	3.9	7.1	3.1	3.1	2.8	2.5
Sr	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500
Ta	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	-1
Tb	0.7	0.9	0.7	-0.5	-0.5	-0.5	0.7	1	-0.5	-0.5	-0.5	0.6	-0.5	-0.5	-0.5	-0.5
Th	9	7.9	8.4	4.4	4.4	4.5	7.8	9.2	5.3	4.9	9	17	5.9	5.7	6	4.5
U	4.7	3.2	3.7	2.5	1.8	2.7	3.3	3.3	1.7	1.4	1.1	3	2	1.9	1.9	1.3
W	-4	-4	-4	-4	25	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
Yb	2.9	3	2.9	1.5	1.4	1.5	2.6	3.3	0.9	1	1.1	1.9	1.4	1.3	1.3	1.2
Zn	70	70	80	60	50	60	-50	120	-50	-50	-50	-50	-50	-50	-50	-50

Table A-1 *continued*. Elemental geochemistry of selected till samples from the surface and subsurface of Stearns County, Minnesota.

Hole	SR-5 *continued*																
Unit	WD	WD	WD	WD	WD	WD	SC	SC	SC	SC	SC	SC	SC	SC	ML	ML	ML
Depth (ft)	16.5	20	23.5	27	30	32.5	36	38.5	40.5	46	53	60	67	74	81	85.5	90
Elements in percent																	
Ca	4	4	4	4	4	4	5	4	5	8	8	8	7	8	9	8	7
Fe	1.4	1.4	1.6	1.4	1.5	1.3	0.9	0.6	0.7	1.4	1.4	1.6	1.4	1.4	1.6	1.5	1.6
Elements in parts per billion																	
Au	-5	46	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
Ir	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
Elements in parts per million																	
Ag	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
As	2	2	2	2	2	3	3	2	-2	3	2	-2	3	-2	-2	2	2
Ba	400	400	500	500	400	400	400	400	300	400	400	400	400	500	400	400	400
Br	2	2	3	3	2	2	3	3	2	3	3	3	3	3	3	3	3
Ce	31	28	32	28	32	27	25	14	14	34	33	38	32	33	34	32	39
Co	7	6	7	6	7	6	5	-5	-5	6	7	7	6	8	6	7	6
Cr	120	130	130	150	130	120	100	110	110	90	120	100	140	150	90	100	80
Cs	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
Eu	0.7	0.7	0.6	0.4	0.4	0.8	0.7	0.4	-0.2	0.5	0.6	0.5	0.5	0.6	0.5	0.7	0.4
Hf	4	4	4	3	4	4	6	1	1	5	4	4	3	4	3	4	4
La	17	15	18	15	17	15	14	8	8	18	18	20	17	18	19	19	22
Lu	0.17	0.14	0.19	0.13	0.17	0.14	0.16	0.05	0.06	0.14	0.14	0.13	0.15	0.17	0.15	0.16	0.17
Mo	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
Na	12000	12000	12000	13000	12000	12000	11000	12000	11000	9900	9600	9800	10000	10000	9000	9800	9900
Nd	10	10	10	10	10	10	10	-10	-10	10	10	10	10	10	10	10	10
Ni	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100
Rb	30	30	50	40	40	40	-30	-30	-30	40	50	50	30	30	40	40	40
Sb	0.3	0.2	0.3	0.2	0.3	0.2	0.2	-0.2	-0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2
Sc	4.5	4.3	5.1	4.4	4.6	4	3.4	1.6	1.8	4.4	4.5	4.6	4.4	4.6	4.9	4.7	5
Se	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
Sm	2.2	2	2.4	2	2.2	2	2	0.8	0.9	2.3	2.3	2.5	2.2	2.2	2.3	2.3	2.6
Sr	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500
Ta	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Tb	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Th	4.4	3.3	4.3	3.6	4.3	3.5	3.6	1.5	1.9	4.7	4.9	5.7	4.5	5	5.2	5.1	5.2
U	1.1	1	1.3	1	1	1	1.5	0.5	0.5	1.7	1.4	1.5	1.2	1.4	1.1	1.1	1.3
W	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
Yb	1.2	0.9	1.2	0.9	1	1	1	0.3	0.4	1	0.9	1	0.9	0.8	0.9	1	1
Zn	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50

Table A-1 *continued.* Elemental geochemistry of selected till samples from the surface and subsurface of Stearns County, Minnesota.

Hole	SR-5 *continued*																
Unit	ML	ML	ML	ML	ML	FR	FR	FR	FR	FR	EB	EB	EB	EB	EB	EB	EB
Depth (ft)	94.5	99	103	105.5	108	111	113	116	118.5	121	124	127.5	130	132	134.5	137.5	140
Elements in percent																	
Ca	7	5	3	2	2	3	1	2	1	3	5	4	4	4	4	4	5
Fe	1.4	1.7	2	2.1	2.1	3.3	1.6	1.3	1.7	2.6	2.2	1.6	2	3.2	0.8	1.8	1
Elements in parts per billion																	
Au	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	5
Ir	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
Elements in parts per million																	
Ag	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
As	-2	2	5	6	8	3	2	-2	-2	2	2	-2	-2	2	-2	2	-2
Ba	400	500	600	600	600	300	300	300	300	400	400	400	400	400	400	400	400
Br	3	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	3
Ce	31	39	50	53	49	32	25	22	23	29	56	50	73	54	18	23	18
Co	6	8	9	8	8	12	6	5	5	11	7	5	6	10	-5	8	-5
Cr	60	80	80	100	90	160	160	140	140	230	110	190	150	140	140	390	200
Cs	-3	-3	3	-3	3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
Eu	0.5	0.8	0.9	1	0.7	0.5	0.4	0.5	0.3	0.8	1.1	0.8	1	0.9	0.5	0.3	0.3
Hf	3	5	6	6	6	4	3	4	4	3	12	10	25	6	2	2	1
La	17	22	28	30	27	16	13	12	13	15	28	25	38	28	10	12	10
Lu	0.15	0.2	0.31	0.33	0.3	0.17	0.15	0.15	0.16	0.17	0.37	0.32	0.45	0.3	0.09	0.1	0.11
Mo	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	9	-5	-5	-5	-5
Na	9900	10000	8800	9200	9000	12000	7800	7900	7700	10000	7000	8100	8600	7100	9600	8500	11000
Nd	10	10	20	20	20	10	10	10	10	10	20	20	30	20	-10	10	-10
Ni	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100
Rb	40	40	50	70	60	30	-30	30	30	40	30	40	-30	60	30	40	40
Sb	0.2	0.4	0.5	0.6	0.6	0.3	0.3	0.2	0.3	0.3	0.6	0.4	0.5	0.5	0.2	0.3	0.2
Sc	3.9	5.9	7	7.3	6.8	7.5	3.9	3.4	2.9	6.6	5.3	4.3	4.8	7.4	2.2	3.5	2.2
Se	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
Sm	2	2.9	3.7	4	3.7	2.3	1.8	1.6	1.8	2.4	4.8	4.3	5.5	4.3	1.3	1.7	1.3
Sr	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500
Ta	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Tb	-0.5	-0.5	-0.5	0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	0.6	0.5	0.7	0.5	-0.5	-0.5	-0.5
Th	4.3	6	7	8.6	7.4	3.7	2.7	2.4	3.2	3.6	6.5	5.9	10	7.4	2.1	2.9	2.1
U	0.9	1.4	1.8	1.9	1.9	0.8	0.7	0.9	0.8	0.9	2.3	1.9	2.6	2.1	0.9	1.1	0.8
W	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	25	-4	-4	-4	-4	31	-4
Yb	0.9	1.3	1.9	2	1.8	1.2	0.9	0.9	0.9	1.2	2.5	2.1	2.9	1.9	0.6	0.7	0.6
Zn	-50	-50	-50	-50	50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50	-50

Table A-1 *continued*. Elemental geochemistry of selected till samples from the surface and subsurface of Stearns County, Minnesota.

Hole	SR-5 *continued*																
Unit	EB	EB	EB	EB	EB	EB	EB	EB	EB	EB	EB	EB	EB	EB	EB	EB	PC
Depth (ft)	147.5	151	154	156.5	159	162	166	169.5	173	176.5	180	184	186	188.5	192	195	198
Elements in percent																	
Ca	12	7	6	5	7	7	7	4	4	4	4	1	3	3	5	5	1
Fe	3.2	1.9	1.9	2	1.9	2.1	2.9	2.5	3.4	3.8	3.2	2.5	3	3.1	2.4	2.8	5.4
Elements in parts per billion																	
Au	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
Ir	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
Elements in parts per milliion																	
Ag	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
As	4	5	7	5	4	6	10	7	13	16	17	10	8	12	4	9	-2
Ba	300	500	400	500	600	400	400	400	400	300	500	400	300	300	200	200	900
Br	3	3	3	3	3	3	4	3	4	3	4	2	4	4	3	4	1
Ce	27	43	42	44	44	43	64	69	73	78	73	55	69	80	55	72	64
Co	10	9	9	9	9	10	13	13	15	16	19	6	11	11	9	12	26
Cr	120	130	130	130	120	120	110	140	110	140	120	180	140	130	210	120	220
Cs	-3	-3	-3	-3	-3	-3	3	3	3	4	3	-3	3	3	-3	-3	-3
Eu	0.7	0.4	0.4	1	0.7	0.7	1.2	1.2	1.4	1.5	1.4	1.2	1.4	1.6	1.1	1.5	1.6
Hf	2	5	5	5	5	5	6	8	8	8	6	9	9	11	7	8	4
La	15	23	22	23	24	23	34	36	38	40	38	27	35	40	28	36	32
Lu	0.13	0.24	0.22	0.24	0.25	0.22	0.33	0.34	0.4	0.43	0.42	0.31	0.41	0.46	0.34	0.41	0.34
Mo	-5	6	-5	-5	-5	-5	7	-5	-5	8	-5	13	8	6	-5	-5	-5
Na	12000	8500	8500	8700	8600	8400	3500	3900	3200	3200	3200	3600	2700	2400	2500	2500	2900
Nd	10	20	20	20	20	20	30	30	30	30	30	20	30	30	20	30	30
Ni	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100
Rb	30	50	50	40	50	60	60	70	70	60	70	40	40	70	50	40	70
Sb	0.4	0.4	0.4	0.4	0.4	0.5	0.8	0.6	0.9	1	1	0.7	0.7	0.9	0.5	0.6	-0.2
Sc	5.4	6.1	5.7	6.1	6.5	6.3	9	9.1	10.1	11	10.3	6.5	8	9.6	6.8	8.5	27.2
Se	7	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	5	-5
Sm	2.1	3.3	3.2	3.2	3.4	3.3	5.3	5.8	6.1	6.6	6.2	5	6.5	7	5.3	7.2	5.7
Sr	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500	-500
Ta	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Tb	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	0.5	0.7	0.8	0.8	0.8	0.7	0.8	1	0.7	0.9	0.7
Th	3.8	5.7	5.6	5.5	6.1	6.2	9.6	8.9	9.6	10	9.4	8.1	8.8	11	6.1	9.1	8.2
U	1.5	2.6	1.7	1.8	1.9	2	3.8	3.6	4.6	4.9	5	5.9	4.4	5.4	4.2	7.1	3.7
W	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
Yb	0.9	1.5	1.4	1.6	1.6	1.4	2.2	2.4	2.6	2.8	2.7	2	2.6	2.9	2.3	2.6	2.4
Zn	-50	50	-50	-50	50	-50	60	50	60	60	60	60	50	70	50	80	80

Table A-1 ***continued.*** Elemental geochemistry of selected till samples from the surface and subsurface of Stearns County, Minnesota.

Hole	SR-6				SR-7			
Unit	WD	K	K	K	WD	WD	WD	WD
Depth (ft)	39	69	74	83	57.5	61.5	65	105
Elements in percent								
Ca	3	3	18	1	8	4	2	3
Fe	2.3	4.7	2.2	4	1.4	2.2	2	4.2
Elements in parts per billion								
Au	-5	-5	-5	-5	-5	-5	-5	-5
Ir	-20	-20	-20	-20	-20	-20	-20	-20
Elements in parts per million								
Ag	-5	-5	-5	-5	-5	-5	-5	-5
As	6	23	19	13	4	2	4	17
Ba	400	400	200	400	400	400	500	400
Br	2	4	13	2	3	3	2	5
Ce	60	82	46	98	33	43	38	82
Co	9	14	10	14	7	9	35	17
Cr	110	110	60	110	90	150	150	120
Cs	4	7	3	7	-3	-3	-3	5
Eu	1.1	1.3	0.6	1.4	0.4	0.8	0.6	1.6
Hf	6	6	2	7	4	6	7	6
La	31	43	26	49	18	22	19	42
Lu	0.3	0.43	0.12	0.5	0.17	0.24	0.24	0.4
Mo	-5	8	69	-5	-5	-5	-5	13
Na	6200	1800	900	2000	10000	10000	6500	2400
Nd	20	30	20	40	10	20	10	30
Ni	-100	-100	-100	-100	-100	-100	-100	-100
Rb	70	120	60	130	40	70	50	80
Sb	0.8	1.2	4.1	0.5	0.3	0.4	0.4	1.1
Sc	8.3	13.5	7.2	14.6	4.4	6.8	5	12.4
Se	-5	-5	-5	-5	-5	-5	-5	-5
Sm	4.4	6.3	3.2	7.4	2.5	3.4	3.1	6.9
Sr	-500	-500	-500	-500	-500	-500	-500	-500
Ta	1	1	1	1	-1	-1	1	1
Tb	0.6	0.8	-0.5	0.9	-0.5	-0.5	-0.5	0.9
Th	8.3	11	6.2	12	4.7	5.5	4.8	11
U	3.5	5.4	19.4	2.6	2.3	1.7	1.7	4.7
W	-4	-4	-4	-4	-4	-4	420	-4
Yb	1.9	2.9	1.3	3.3	1	1.6	1.7	2.8
Zn	80	70	70	80	-50	-50	-50	50

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